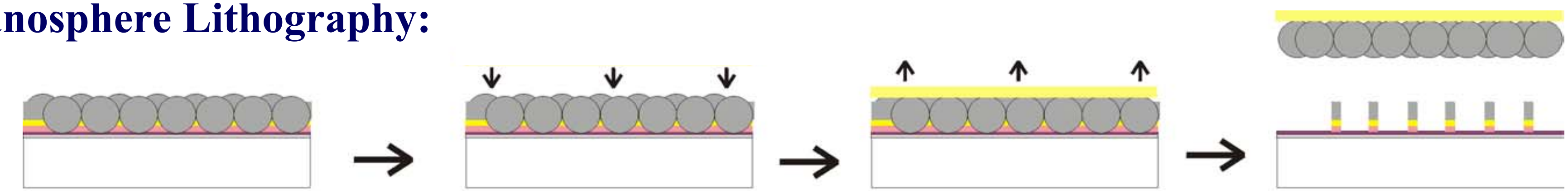
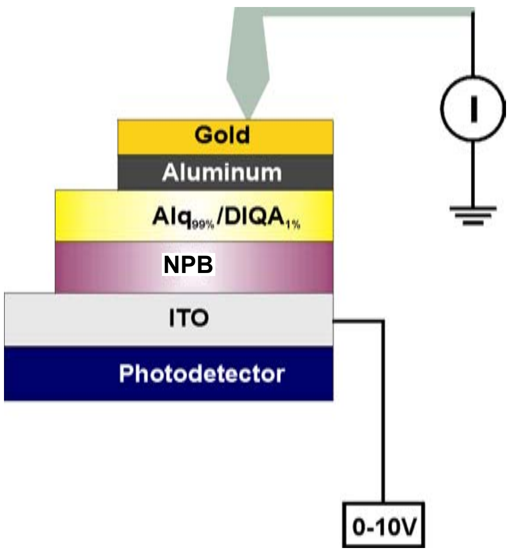
Electronic and Photonic Characterization of Nanopatterned Organic Light Emitting Diodes

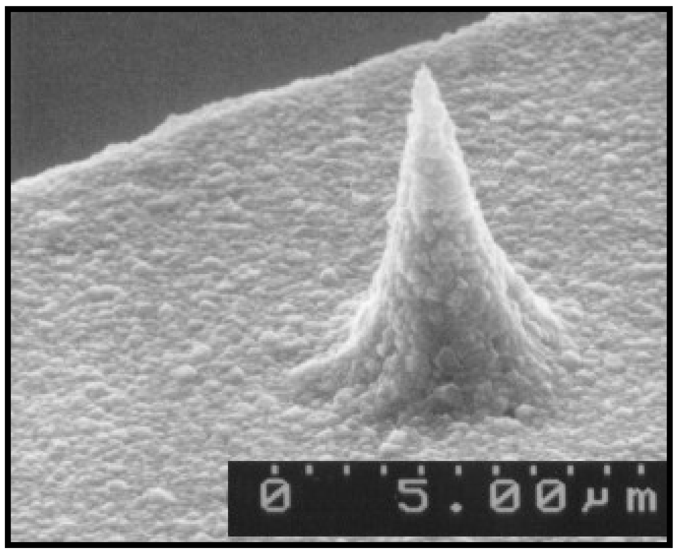
Nanosphere Lithography:



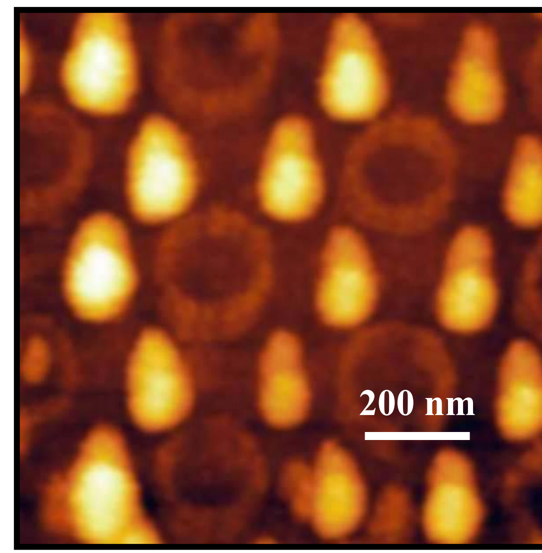
Self-assembled Bead Mask → OLED Deposition → Bead Lift-off → Nano-OLED Pixels



Conductive AFM Apparatus



Conductive Diamond Coated AFM Tip



AFM Image of 90 nm OLED Pixels

CAREER: Nanoelectronic and Nanophotonic Characterization of Hybrid Hard and Soft Materials; Mark C. Hersam, Assistant Professor, Department of Materials Science and Engineering, Northwestern University; DMR-0134706.

Due to their high quantum efficiencies, ease of fabrication, and color tunability, organic light emitting diodes (OLEDs) have attracted considerable interest for display technologies. Unlike inorganic LEDs whose optoelectronic properties are dominated by a spatially dependent bandstructure, charge transport in OLEDs is dominated by carrier hopping. Consequently, OLEDs are expected to be relatively immune to size-dependent property changes. Until recently, however, nanoscale OLEDs had not been fabricated, so this immunity to size-dependent effects was not verified experimentally. Therefore, the goal of this project is to fabricate and characterize nano-OLEDs in effort to determine the fundamental spatial limits of this technology. Ultimately, nano-OLEDs will enable ultra-high density pixels with built-in redundancy, thus improving the resolution and reliability of display technologies.

The PowerPoint slide illustrates the nanopatterning and nanocharacterization strategy for the aforementioned OLED devices. The top figure schematically depicts nanosphere lithography (NSL) that was accomplished in collaboration with Professor Tobin Marks of the Northwestern University Department of Chemistry. The first step of NSL is to form a self-assembled, hexagonally close-packed monlayer of 400 nm diameter polystyrene beads on an indium-tin-oxide (ITO) surface. The OLED device structure is then deposited through the interstices of this monolayer. Following lift-off of the polystyrene beads, 90 nm diameter OLED pixels are patterned on the surface. These individual pixels can then be directly addressed with conductive atomic force microscopy (AFM). In the conductive AFM apparatus, a boron-doped diamond coated AFM tip is used to inject charge carriers into the OLED structure. The OLED current and photon emission (detected with a photon detector mounted below the ITO substrate) is continuously monitored during imaging, thus enabling nanoscale spatial mapping of voltage-dependent conductivity and quantum efficiency of the nano-OLED array. The final two figures display an SEM image of the conductive diamond coated AFM tip and an AFM image of the nano-OLED pixel array.

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Individuals Supported by NSF:

Professor Mark Hersam's group at Northwestern University (DMR-0134706) is engaged in the fabrication and characterization of nanopatterned soft materials (organic, polymeric, and biological molecules) on inorganic substrates. Prof. Hersam's NSF CAREER grant directly supports one graduate student (Liam Cavanaugh, first year graduate student in Materials Science and Engineering) and two undergraduate students (Maryjoy Carnate and Matthew Schmitz, both of whom are junior undergraduates in Materials Science and Engineering). Maryjoy Carnate is a female student from the University of Illinois at Urbana-Champaign who is spending the Summer 2002 Quarter in Prof. Hersam's laboratory under the support of a REU supplement. Matthew Schmitz will also be supported by a REU supplement during the Summer 2002 Quarter.

Recent Awards and Honors:

Professor Mark Hersam has recently received the following awards and honors:

National Science Foundation CAREER Award, 2001-2006
Arnold and Mabel Beckman Young Investigator Award, 2001-2004
Finalist for the Discover Magazine Innovation Award in Electronics, 2001
Searle Center for Teaching Excellence Junior Fellow, 2001-2002
Review of Scientific Instruments Editorial Board Member, 2001-2003

Outreach Activities:

Professor Mark Hersam has recently been involved with the following outreach activities:

(1) Development of a web-based undergraduate/graduate course entitled Materials Science and Engineering 395 – Nanomaterials: MSE 395 – Nanomaterials was offered for the second time in the Spring 2002 Quarter. This highly interdisciplinary course attracted 19 students (9 undergraduates and 10 graduate students) from 5 departments (Materials Science and Engineering, Chemical Engineering, Electrical and Computer Engineering, Mechanical Engineering, and Chemistry). In addition to teaching students about structure-property relationships and materials processing techniques at the nanometer length scale, this course also promoted interdisciplinary collaboration among students through a variety of group activities. All lecture notes are available in electronic format on-line, thus allowing the course to be easily exported to other institutions in the future.

(2) Director of the Nanoscale Science and Engineering Center (NSEC) Research Experience for Undergraduates (REU) Program: The NSEC REU program will begin its first summer on June 24, 2002. This nine week program provides a nanotechnology

research experience for nine undergraduate students from a variety of institutions including Michigan State University, Northwestern University, Knox College, Cal Poly State University, Loyola University, and North Park University. Four of the students are women and three of the students are from relatively small institutions that do not have comparable opportunities for undergraduate research. The REU program is also directly affiliated with the Minority Internships in Nanotechnology (MIN) program that has attracted an additional eight underrepresented minority undergraduate students.

(3) Member of the Northwestern University Materials Research Science and Engineering Center (MRSEC) Nanotechnology Materials World Module (MWM) Committee: The MRSEC MWM program develops interactive, design-based curricular materials for high school teachers. The MWM committee has developed a new nanotechnology module that is currently being alpha tested at several high schools in the Chicagoland area. One of the participating high school teachers, Neil Schmidgall from Glenbrook South High School, will be spending the summer in Prof. Hersam's lab to further develop the nanotechnology module.

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Nano Organic Light Emitting Diodes – So What?

Due to their high quantum efficiencies, ease of fabrication, and color tunability, organic light emitting diodes (OLEDs) have attracted considerable interest for display technologies. Unlike inorganic LEDs whose optoelectronic properties are dominated by a spatially dependent bandstructure, charge transport in OLEDs is dominated by carrier hopping. Consequently, the emitted optical wavelengths from OLEDs are expected to be relatively immune to size-dependent effects. However, it has been shown recently that OLEDs can sustain substantially higher current densities before failure when they are fabricated at the micron rather than millimeter length scale [1]. It is believed that this improved performance results from better thermal management in small devices. Our preliminary data on nanopatterned OLEDs show further improvements in device performance and reliability. Consequently, nano-OLEDs are likely to outperform current OLED technology.

Furthermore, by using nanopatterned OLEDs, many devices can be packed into the space currently occupied by one pixel in a modern display. This improved density enables high-density displays with built-in redundancy. In other words, with nano-OLEDs, each pixel can have several light emitting devices – so, when one fails, the next device in the pixel can be activated. This approach also holds promise for improving the lifetime and reliability of OLED-based displays.

[1] C. I. Wilkinson, D. G. Lidzey, L. C. Palilis, R. B. Fletcher, S. J. Martin, X. H. Wang, and D. D. C. Bradley, "Enhanced performance of pulse driven small area polyfluorene light emitting diodes," *Appl. Phys. Lett.*, **79**, 171 (2001).